PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : G06F 9/18, 15/40, 13/00, 12/14, 17/30, 13/14

A1

(11) International Publication Number: WO 99/00725

(43) International Publication Date: 7 January 1999 (07.01.99)

(21) International Application Number: PCT/US98/13652

(22) International Filing Date: 30 June 1998 (30.06.98)

(30) Priority Data:
08/887,339 30 June 1997 (30.06.97) US

(71) Applicant: SUN MICROSYSTEMS, INC. [US/US]; 901 San Antonio Road, Palo Alto, CA 94303 (US).

(72) Inventor: KLUGE, Kevin, L.; 10190 Parkwood Drive, Cupertino, CA 95014 (US).

(74) Agents: HYMAN, Eric, S. et al.; Blakely, Sokoloff, Taylor & Zafman, 7th floor, 12400 Wilshire Boulevard, Los Angeles, CA 90025-1026 (US).

(81) Designated States: CN, JP, KR, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

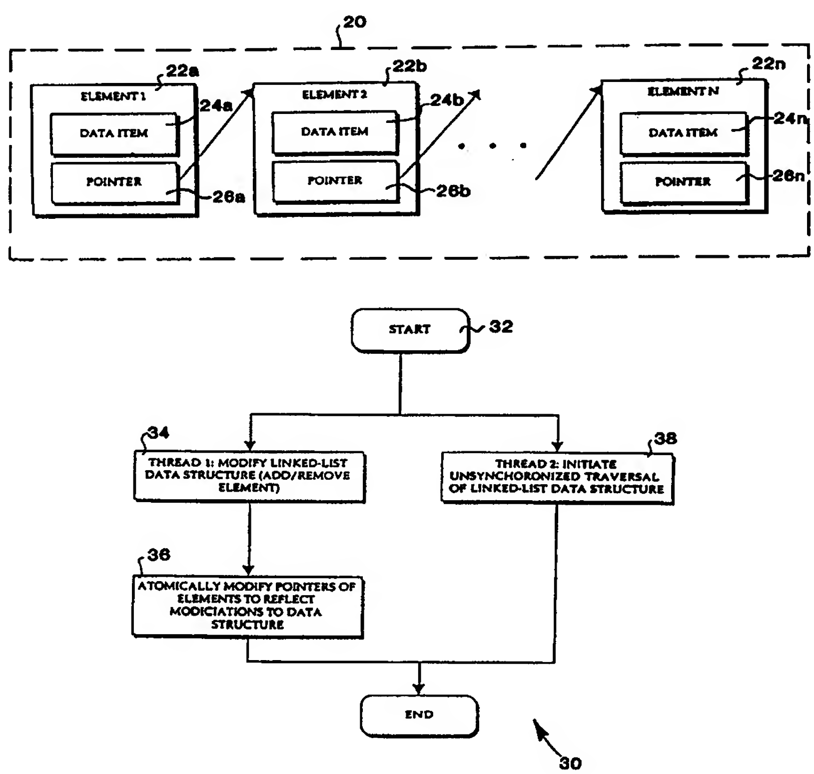
Published

With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: METHOD AND APPARATUS FOR MANAGING A LINKED–LIST DATA STRUCTURE

(57) Abstract

A method of managing a linked–list data structure (20) is disclosed. The linked–list data structure (20) has a number of elements (22a, 22b...22n), each of which includes a data item (24a, 24b...24n) and a pointer (26a, 26b...26n) to a sequentially following element. The method allows the modification of the linked–list data structure (20), either by the insertion or removal of element therefrom (34), while permitting concurrent and unsynchronized traversal operations with respect to the linked–list data structure (20). Specifically, the method requires that the pointers (26a, 26b...26n) of elements (24a, 24b...24n) within the linked–list data structure (20) be modified using an atomic operation (36) to reflect any modifications made to the linked–list data structure (20). The utilization of atomic operations to update the pointers (26a, 26b...26n) ensures that the unsynchronized traversal operations (38) examine a valid data path.



METHOD AND APPARATUS FOR MANAGING A LINKED-LIST DATA STRUCTURE

FIELD OF THE INVENTION

The present invention relates generally to the field of computer software programs and, more specifically, to a method of managing a linked-list data structure maintained and accessed by a computer program.

BACKGROUND

Linked-list data structures store sequences of data elements, and provide the ability to rapidly add and remove data elements from such sequences. Linked-list data structures are characterized in that each element thereof includes a pointer to the next sequential element in the linked-list. Accordingly, it will be appreciated that the addition of an element to, or the removal of an element from, the linked-list data structure requires that the pointer of the immediately preceding element be updated to reflect the modification to the linked-list data structure.

Multi-threaded programs include a number of threads, a number of which may require access to a particular linked-list data structure. Such threads may perform either non-modifying operations, such as GETs, or modifying operations, such as ADDs, with respect to the linked-list data structure. In order to prevent simultaneous accesses by a number of threads to an object, such as a link-listed data structure, it is common practice for such threads to implement so-called "synchronized" methods, which perform a lock action on the target object, thus preventing any other methods from gaining access to the target object until that object is again unlocked by the active method.

Where the target object is a linked-list data structure, this entire data structure is thus typically locked by a synchronized method until that method completes. Accordingly, concurrent accesses by different threads to a linked-list data structure are prohibited.

SUMMARY OF THE INVENTION

According to a first aspect of the invention, there is provided a method of managing a linked-list data structure. The linked-list data structure includes a first element having both a data portion and a pointer portion. The method requires the modification of the linked-list data structure by either the insertion or removal of a second element. The pointer portion of the first element is then updated to reflect the modification to the linked-list data structure. This updating of the pointer portion of the first element comprises an atomic operation. Concurrently with the modification of the

linked-list data structure, an unsynchronized traversal of the linked-list data structure is performed. In one embodiment, the traversal operation is a non-modifying operation, and comprises a data read and/or retrieval operation.

According to a second aspect of the invention, there is provided a computer-readable medium having stored thereon a sequence of instructions which, when executed by a processor, cause the processor to perform the steps of the method as described above.

According to a third aspect of the invention, there is provided, in an object-oriented programming environment, a linked-list object. The object includes a linked-list data structure, and a modifying method which modifies the linked-list data structure by the insertion or removal of a first element. The object also includes an updating method which updates a pointer portion of a second element to reflect modifications made to the linked-list data structure by the modifying method. The updating steps performed by the updating method comprise an atomic operation. The object also includes a traversal method which performs an unsynchronized traversal of the linked-list data structure concurrently with the modification of the link-list data structure by the modifying method. The traversal may perform an inspection of the pointer portion of the first element as an atomic operation.

Other features on the present invention will be apparent from the accompanying drawings, the detailed description and the claims which follow.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention is illustrated by way of example and not limitation in the figures of the accompanying drawings, in which like references indicate some of the elements and in which:

Figure 1 is a block diagram showing a multi-threaded program operating in an object-oriented program environment.

Figure 2 is a schematic representation of a linked-list data structure.

Figures 3a and **3b** are schematic illustrations showing respective element insertion and removal operations performed with respect to the linked-list data structure shown in **Figure 2**.

Figure 4 is a flow chart illustrating a method, according to one embodiment of the present invention, of managing a linked-list data structure.

Figure 5 is a block diagram illustrating the structure of a hash table.

Figure 6 is a block diagram illustrating a series of hash table objects, constructed according to one embodiment of the present invention.

Figure 7 is a block diagram illustrating a computer system including a computer-readable medium having stored thereon a sequence of instructions which, when executed by a processor of the computer system, cause the processor to perform a

method of managing a linked-list data structure according to one embodiment of the present invention.

DETAILED DESCRIPTION

A computer-implemented method of managing a linked-list data structure is described. In the following description, for the purposes of explanation, a number specific details are set forth in order to provide a thorough understanding of the present invention. It will be evident, however, to one skilled in the art that the present invention may be practiced without these specific details. Specifically, while one exemplary embodiment is described below as being implemented in an object-oriented programming language, the invention is not restricted to this or any other programming language type.

Referring to **Figure 1**, there is shown a block diagram of a multi-threaded program (10) created in an object-oriented program language, such as the Java™ programming language developed by Sun Microsystems of Mountain View, California. The program 10 is shown to maintain a thread queue 12 of threads 14b, 14c and 14d, which require access to an object 16. A thread 14a is shown currently to have access to the object 16. The multi-threaded program 10 is characterized in that each of the threads 14 share data, and thus may have access to common data and variables, which may be contained in an object such as the object 16. For example, in the Java™ programming language, a Java Virtual Machine (JVM) may support many threads of execution at any one time. Each of these threads independently executes Java code that operates on values and objects residing in a shared memory. Multiple-threads may be supported by having multiple hardware processes, by time-slicing a single hardware processor, or by time-slicing many hardware processors.

An active thread 14 may have access to any object to which it has a reference. For example, each of the threads 14a-d has a reference to object 16. Where two or more threads have access to a common object, it is conceivable that operations performed by each of these threads may collide and result in corruption of the relevant object or a malfunction of either or both of the threads. To address this problem, it is common practice to specify "synchronized" access to shared objects by multiple threads. Specifically, the term "synchronized" refers to the ability to ensure that one thread has completed an operation, with respect to an object, variable or data, without interruption. The use of semaphores or mutexes can be used to implement synchronization. Alternatively, synchronization between thread accesses can be obtained by the use of "monitors", which are high-level mechanisms for allowing only one thread at a time to execute a region of code protected by the relevant monitor. In the Java™ language, an object that is capable of blocking threads, and then again notifying the blocked threads when it becomes available, is termed a monitor object. For example, referring to **Figure 1**, the object 16 may be a monitor object, in which case it will block threads 14b-c when

thread 14a has access thereto, and will notify the thread queue 12 when the thread 14a has completed its access to the object 16. The action of blocking access by other threads to an object is referred to as performing a "lock", and the action of again allowing access to an object by another thread is referred to as an "unlocked" operation.

It will be appreciated that threads executing synchronized methods suffer a performance disadvantage in that only a single thread can access an object at any one time, thus certain concurrent operations may be prohibited.

A common data structure type which is incorporated within objects 16 is the linked-list data structure 20, as illustrated in **Figure 2**. The linked-list data structure 20 comprises an ordered sequence of elements 22a-22n, and facilitates the rapid insertion and removal of elements from this sequence. Each element 22 comprises a data item 24 and a pointer 26 to the next sequential element 22 in the linked-list data structure 20. The last element 22n in the data structure 20 has a null pointer to denote the end of the list.

Figures 3a and **3b** illustrate modifications of a link-list data structure 20. Specifically, **Figure 3a** illustrates the insertion of an element 22 (n+1) into the data structure 20 between elements 22(n) and 22(n+2). **Figure 3b** similarly shows the removal of an element 22(n+1) from a linked-list data structure 20. Referring firstly to **Figure 3a**, an active thread having access to an object including the linked-list data structure 20 may wish to insert the element 22(n+1). The insertion (or addition) of such an element into the linked-list data structure 20 requires that the pointer of the element 22(n), which immediately precedes the location into which the element 22(n+1) is to be inserted, be updated to point from the previously-sequential element 22(n+2) to the newly inserted element 22(n+1). This updating of the pointer of element 22(n) is indicated by arrow 28. The pointer of the inserted element 22(n+1) must also be set to point to element 22(n+2).

In one embodiment of the present invention, each pointer 26 comprises a 32-bit address. The need for synchronization in a program becomes apparent when considering the hypothetical in which two threads are simultaneously accessing the linked-list data structure 20. Specifically, consider that a first thread, which is inserting the element 22(n+1), is updating the pointer 26 of the element 22(n) to point to the newly inserted element 22(n+1). Simultaneously, a second thread may be performing a traversal of the data structure 20 by examining the data path specified thereby. Specifically, the second thread may be traversing the data structure 20 with a view to retrieving a predetermined data item 24. As the second thread is dependent on the pointer of each element to direct it to the next element in the sequence, it will be appreciated that a read operation, performed on a partially modified pointer, would prove disastrous to the traversal of the data structure 20 by the second thread. In order to prevent a scenario such as that outlined above, it has been common practice to synchronize methods of objects which access linked-list data structures 20, so that only one thread or method has access to the data

structure 20 at any one time. Specifically, synchronization may be utilized to obtain a lock on a data structure, such as hash table, which references a linked-listed data structure, or directly on the linked-list data structure 20 itself. It will, however, be appreciated that allowing only one method at a time to access the linked-list data structure does not provide optimum performance. To appreciated the significance of the present invention, three operations which may be performed with respect to a linked-list data structure 20 must be considered, namely:

1. An insertion (or addition) operation, wherein an element is added to the linked-list data structure 20 as illustrated in **Figure 3a**;

2. A removal (or deletion) operation wherein an element is removed from the data structure 20 as illustrated in **Figure 3b**; and

3. A traversal operation, in which the contents of elements within the data structure 20 are examined with a view to establishing the presence of a certain data item therein and/or possibly to retrieve such a data item.

A traversal operation is distinguished from the insertion and removal operations in that no modification to the data structure 20 occurs. The present invention proposes a method in which non-modifying traversals of the linked-list data structure 20 are unsynchronized with respect to other traversal operations and with respect to modify operations. The implementation of unsynchronized traversal operations is advantageous in that modify and traversal operations can occur concurrently, and in that a number of unsynchronized traversals of the linked-list data structure 20 can also occur concurrently. Thus, in programs in which multiple threads perform primarily traversal operations on a linked-list data structure 20, a large number of these threads are able concurrently to access the data structure 20. The implementation of unsynchronized traversal operations is facilitated by the specification of atomic read and write operations by threads of the pointers 26 of elements 22. Specifically, an atomic operation is considered to be functionally indivisible and is thus ensured to complete. The methodology of the present invention will now be described with specific reference to **Figures 3a** and **b**. The insertion method illustrated in **Figure 3a** is synchronized (with respect to other synchronized methods), and comprises, inter alia, the following steps:

1. Checking whether the element to be inserted already exists within the linked-list structure 20. If so, the insertion operation may be aborted.

2. In an atomic operation, the pointer of the inserted element 22(n+1) is updated to point to the next sequential element 22(n+2). On completion of this step, both elements 22(n) and 22(n+1) point to the same element 22(n+2).

3. In an atomic operation, the pointer of element 22(n) is updated to point to the inserted element 22(n+1).

Similarly, the synchronized method of removing an element 22 from the linked-list data structure 20 may comprise, inter alia, the following steps:

1. Performing a check operation to establish whether the relevant data item is in fact contained in the linked-list; and

2. In an atomic operation, setting the pointer of element 22(n) to point to the element 22(n+2).

In the operations performed above, it should be noted that the modifications to the pointers 26 of the elements 22 comprise atomic operations. Accordingly, any method performing a traversal operation of the linked-list data structure 20 during either such insertion or deletion operations will be guaranteed to examine a valid data path. It is this guarantee of a valid data path which facilitates access to the linked-list data structure 20 by methods implementing unsynchronized traversal operations. However, in one embodiment, it will be appreciated that synchronized modifying operations are still required to prevent collisions between such modifying operations. The use of unsynchronized traversal methods thus allows a number of threads incorporating such unsynchronized traversal methods concurrently to access a single linked-list data structure 20, and in this way to optimize performance of a computer program.

The present invention is furthermore particularly suited for use in programming languages which have the capability to implement so-called "mark and sweep garbage collection". Specifically, such mark and sweep garbage collection techniques do not require that reference counter mechanisms be implemented to maintain a tracking of references to a specific object. Garbage collection schemes which employ reference counting require synchronized operations and may accordingly limit the performance advantage achieved by the present invention when performing a synchronized garbage collection operation.

Referring now to **Figure 4**, there is illustrated a method 30, according to the present invention, of managing a linked-list data structure 20 including a number of elements 22. The method commences at step 32 and then proceeds to perform in two sets of operations in parallel. Specifically, the method 30 allows a first thread, at step 34, to modify the linked-list data structure 20 by the insertion or removal of an element 22. The method 30 then proceeds to step 36, wherein pointers of pertinent elements 22 within the data structure 20 are atomically modified to reflect the modification made at step 34. In one embodiment of the invention, the programming language which facilitates the atomic modification and reading of the pointers 26 is the Java™ programming language. Concurrently with the performance of steps 34 and 36, the method 30 of the present invention allows the concurrent performance of any number of unsynchronized traversal operations of the linked-list data structure 20, at step 38.

Figure 5 illustrates a hash table 40, including a number of entries, or buckets 42, each of which may reference a respective linked-list data structure 20. In a hash table data structure, data items that are objects (for example, employee records) are identified by a key. For example, the data item in the first element 22 of the linked-list data

structure 20a is identified by the key "AAA". The hash table 40 computes an integer value derived from the key, which is termed the hash code. The hash code generated from the key "AAA" in the illustrated example is thus zero (0). The hash table 40 thus facilitates the generation of a compact array index. Data items having keys for which a common hash code is generated are viewed as being contained in the same bucket and may comprise a linked-list data structure 20 such as any one of those shown in **Figure 5**. The present invention may be employed to manage a linked-list data structure 20 referenced by the hash table 40.

Figure 6 illustrates a series of objects 50, according to the present invention, which comprise objects of the class 52. Each of the objects 50 is shown to include a hash table data structure 40, which indexes a number of linked-list data structures 20. Each object further includes three unsynchronized traversal methods, namely the "CONTAINS" method 60, the "CONTAINS KEY" method 62, and the "GET" method 64. The "CONTAINS" method 60 tests if a key provided by a thread maps into specified value in the hash table data structure 40. The "CONTAINS KEY" method 62 tests if a specified object is a key in the hash table data structure 40, while the "GET" method 64 returns a data item to which a provided key is mapped in the hash table data structure 40. Each object further includes a synchronized "PUT" method 66 which is responsible for inserting an element 22 into a linked-list data structure 20, according to the methodology described above. Each object 50 also includes a synchronized "REMOVE" method 68, which is responsible for the removal of elements 22 from a linked-list data structure 20, according to the methodology described above. It will, of course, be appreciated that the objects 50 described above are merely exemplary, and the principles of the present invention may be applied to any number of objects of a variety of structures.

Turning now to **Figure 7**, there is shown a computer system 70 including a processor 72, a static memory 74 and a main memory 76. The processor 72, and memories 74 and 76 communicate with each other, and with a number of peripheral devices, over a bus 78. The above mentioned peripheral devices include a video display 80 (such as a cathode ray tube (CTR) or a liquid-crystal display (LCD)), and an alpha-numeric input device 82 (such as a keyboard), a cursor control device 84 (such as a mouse), a drive unit 86 accommodating a computer-readable medium 88, a signal generation device 90 (such as a pair of audio speakers) and a network interface device 94. For the purposes of the present invention, the term "computer-readable medium" shall be taken to refer to a magnetic storage medium which may be accommodated within the drive unit 86, the main memory 76, the static memory 74, the processor 72 or any other medium from which data may be obtained for execution by the processor 72. A hash table object 92, which includes methods such as those described above, it is shown to be residing, either completely or in part, in the computer-readable medium 88, the main memory 76, or in the processor 72 itself. The hash table object 92 includes a

sequence of instructions which, when executed by the processor 72, cause the processor 72 to perform at least the steps described above with reference to **Figure 4.**

The network interface device 94 may be a modem, network adapter card, or any other device for coupling the computer system 70 to a computer network. The network access device 94 may be used to generate or receive a carrier wave having a computer data signal encoded therein, The computer data signal can be interpreted to generate program code that may be executed to implement the present invention.

Thus, a method of managing a linked-list data structure has been described. Although the present invention has been described with reference to specific exemplary embodiments, it will be evident that various modifications and changes may be made to these embodiments without departing from the broader spirit and scope of the invention. Accordingly, the specification and drawings are to be regarded in an illustrative rather than a restrictive sense.

CLAIMS

What is claimed is:

1. A computer-implemented method of managing a linked-list data structure including a first element comprising a data portion and a pointer portion, the method including the steps of:

modifying the linked-list data structure;

updating the pointer portion of the first element to reflect the modification to the linked-list data structure, the step of updating comprising an atomic operation; and

performing an unsynchronized traversal of the linked-list data structure concurrently with the modification of the linked-list data structure.

2. The computer-implemented method of claim 1 including the step of concurrently performing a plurality of unsynchronized traversals of the linked-list data structure.

3. The computer-implemented method of claim 1 wherein the step of modifying the linked-list data structure comprises adding a second element into the linked-list data structure, and wherein the atomic operation includes modifying the pointer portion of the first element to point to the second element.

4. The computer-implemented method of claim 1 wherein the atomic modify operation includes modifying the pointer portion of the first element to point to a third element.

5. The computer-implemented method of claim 1 wherein the step of modifying the linked-list data structure comprises removing a second element from the linked-list data structure, and wherein the atomic operation includes modifying the pointer portion of the first element to point to a third element instead of the second element.

6. The computer-implemented method of claim 1 including the step of performing a mark and sweep garbage collection operation with respect to the linked-list data structure concurrently with the modifying and updating operations.

7. The computer-implemented method of claim 1 wherein the step of modifying the linked-list data structure is a synchronous operation.

8. The computer-implemented method of claim 1 wherein the unsynchronized traversal comprises a retrieval operation to retrieve a data portion of an element within the linked-list data structure.

9. In an object-oriented programming environment, a linked-list object comprising:

a linked-list data structure including a plurality of elements, each element having a respective data portion and a pointer portion;

a modifying method for modifying the linked-list data structure by the insertion or removal of a first element;

an updating method for updating the pointer portion of a second element to reflect the modification to the linked-list data structure utilizing an atomic modify operation; and

a traversal method for performing an unsynchronized traversal of the linked-list data structure concurrently with the modification of the linked-list data structure by the modifying method.

10. A computer-readable medium having stored thereon a sequence of instructions which, when executed by a processor, cause the processor to perform the steps of:

modifying a linked-list data structure, including a first element having data and pointer portions, by the insertion or removal of a second element;

updating the pointer portion of a first element to reflect the modification to the linked-list data structure, the step of updating comprising an atomic operation; and

performing an unsynchronized traversal of the linked-list data structure concurrently with the modification of the linked-list data structure.

11. The computer-readable medium of claim 10 having stored thereon a sequence of instructions which cause the processor to perform a plurality of unsynchronized traversals of the linked-list data structure concurrently with the modification of the linked-list data structure.

12. The computer-readable medium of claim 10 having a sequence of instructions stored thereon which cause the processor to add the second element into the linked-list data structure, wherein the atomic operation includes modifying the pointer portion of the first element to point to the second element.

13. The computer-readable medium of claim 10 wherein the atomic operation includes modifying the pointer portion of the first element to point to a third element.

14. The computer-readable medium of claim 10 having a sequence of instructions stored thereon which cause the processor to remove the second element from the linked-list data structure, and the step of updating comprises the step of atomically modifying the pointer portion of the first element to point to a third element instead of the first element.

15. The computer-readable medium of claim 10 including the step of performing a mark and sweep garbage collection operation with respect to the linked-list data structure concurrently with the modifying and updating operations.

16. The computer-readable medium of claim 10 wherein the step of modifying the linked-list data structure is a synchronous operation.

17. A computer-implemented method of managing a linked-list data structure including an element comprising a data portion and a pointer portion, the method including the steps of:

performing a first operation with respect to the linked-list data structure; and performing an unsynchronized traversal of the linked-list data structure concurrently with the first operation, wherein the unsynchronized traversal includes performing a read of the pointer portion of the element, and the read is performed as an atomic operation.

18. The computer-implemented method of claim 17 wherein the first operation is a further unsynchronized traversal of the linked-list data structure.

19. The computer-implemented method of claim 17 wherein the first operation is a further synchronized modification of the linked-list data structure.

20. A computer-readable medium having stored thereon a sequence of instructions which, when executed by a processor, cause the processor to perform the steps of:

performing a first operation with respect to the linked-list data structure; and performing an unsynchronized traversal of the linked-list data structure concurrently with the first operation;

wherein the unsynchronized traversal includes performing a read of the pointer portion of the element, and the read is performed as an atomic operation.

21. The computer-readable medium of claim 20 wherein the first operation is a unsynchronized traversal of the linked-list data structure.

22. The computer-readable medium of claim 20 wherein the first operation is a further synchronized modification of the linked-list data structure.

23. A computer data signal embodied in a carrier wave and representing a sequence of instructions which, when executed by a processor, cause the processor to perform the steps of:

modifying a linked-list data structure, including a first element having data and pointer portions, by the insertion or removal of a second element;

updating the pointer portion of a first element to reflect the modification to the linked-list data structure, the step of updating comprising an atomic operation; and

performing an unsynchronized traversal of the linked-list data structure concurrently with the modification of the linked-list data structure.

24. A computer data signal embodied in a carrier wave and representing a sequence of instructions which, when executed by a processor, cause the processor to perform the steps of:

performing a first operation with respect to a linked-list data structure including an element comprising a data and pointer portion; and

performing an unsynchronized traversal of the linked-list data structure concurrently with the first operation;

wherein the unsynchronized traversal includes performing a read of the pointer portion of the element, and the read is performed as an atomic operation.

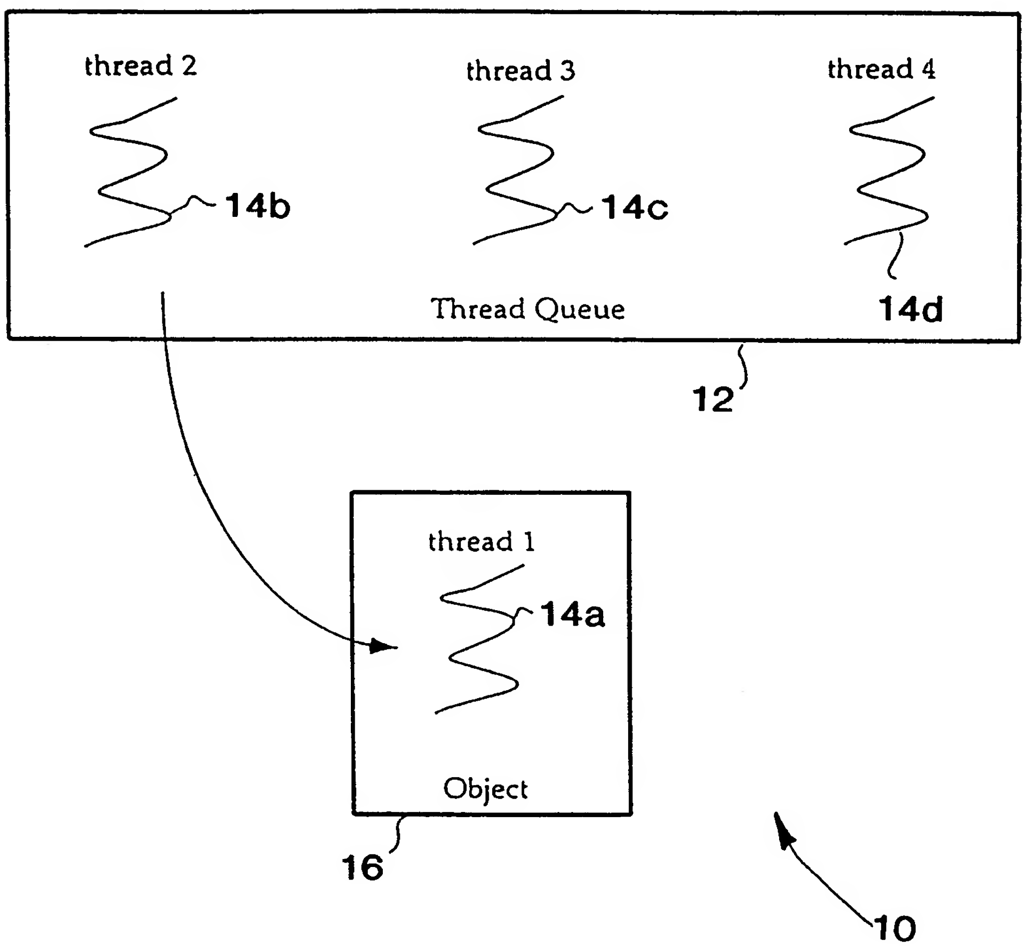

thread 2
14b
thread 3
14c
thread 4
14d
Thread Queue
12
thread 1
14a
Object
16
10

FIG. 1

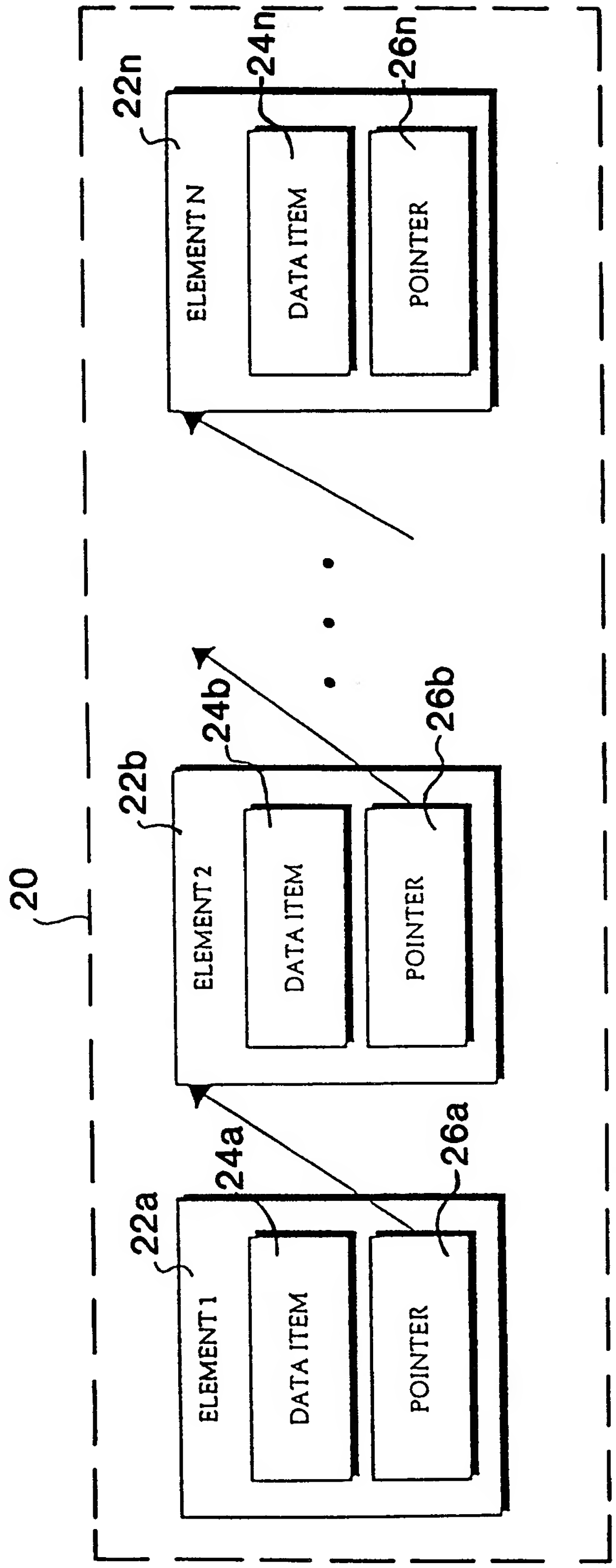

20
22n
24n
26n
ELEMENT N
DATA ITEM
POINTER
22b
24b
26b
ELEMENT 2
DATA ITEM
POINTER
22a
24a
26a
ELEMENT 1
DATA ITEM
POINTER

FIG. 2

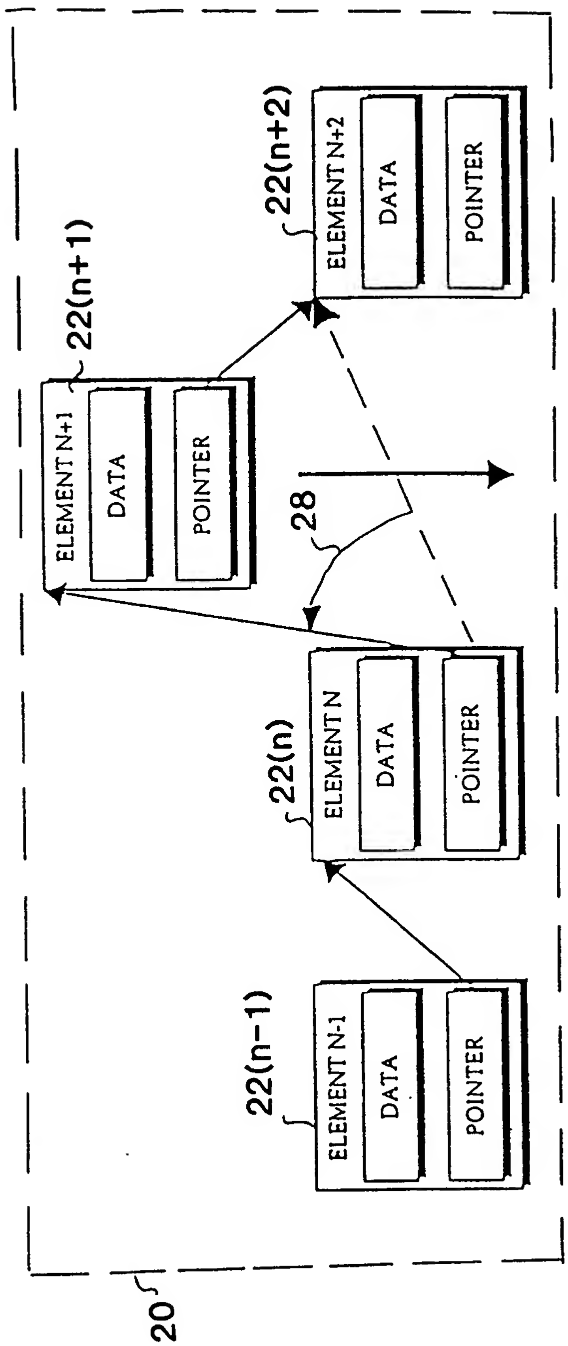

22(n+1)
22(n+2)
ELEMENT N+1
DATA
POINTER
ELEMENT N+2
DATA
POINTER
28
ELEMENT N
DATA
POINTER
22(n)
22(n-1)
ELEMENT N-1
DATA
POINTER
20

FIG. 3a

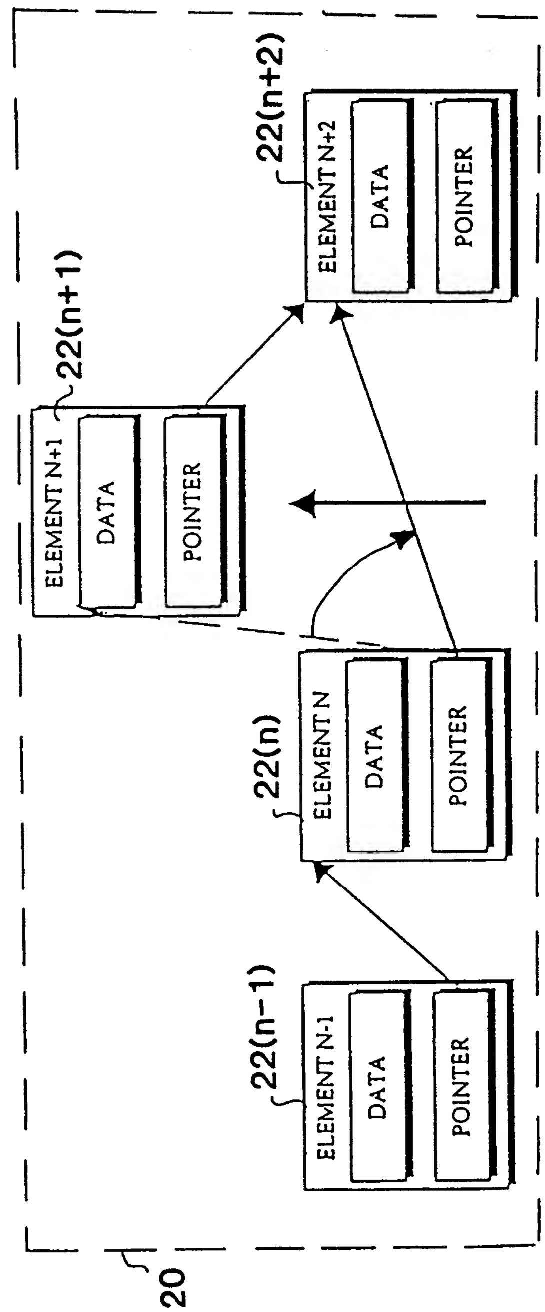

22(n+2)
22(n+1)
ELEMENT N+1
DATA
POINTER
ELEMENT N+2
DATA
POINTER
ELEMENT N
DATA
POINTER
22(n)
22(n-1)
ELEMENT N-1
DATA
POINTER
20

FIG. 3b

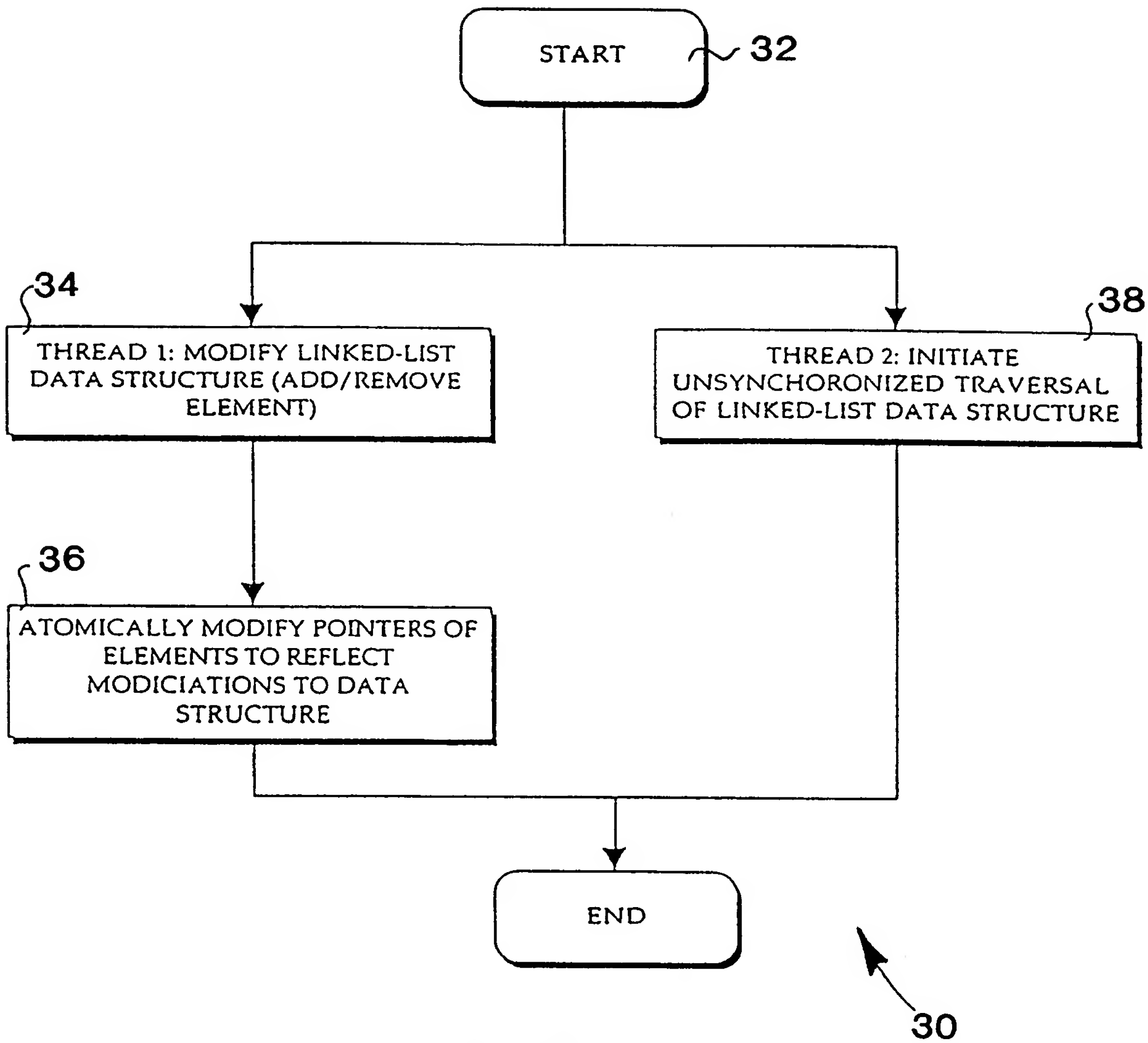

START
32
34
THREAD 1: MODIFY LINKED-LIST DATA STRUCTURE (ADD/REMOVE ELEMENT)
38
THREAD 2: INITIATE UNSYNCHORONIZED TRAVERSAL OF LINKED-LIST DATA STRUCTURE
36
ATOMICALLY MODIFY POINTERS OF ELEMENTS TO REFLECT MODICIATIONS TO DATA STRUCTURE
END
30

FIG. 4

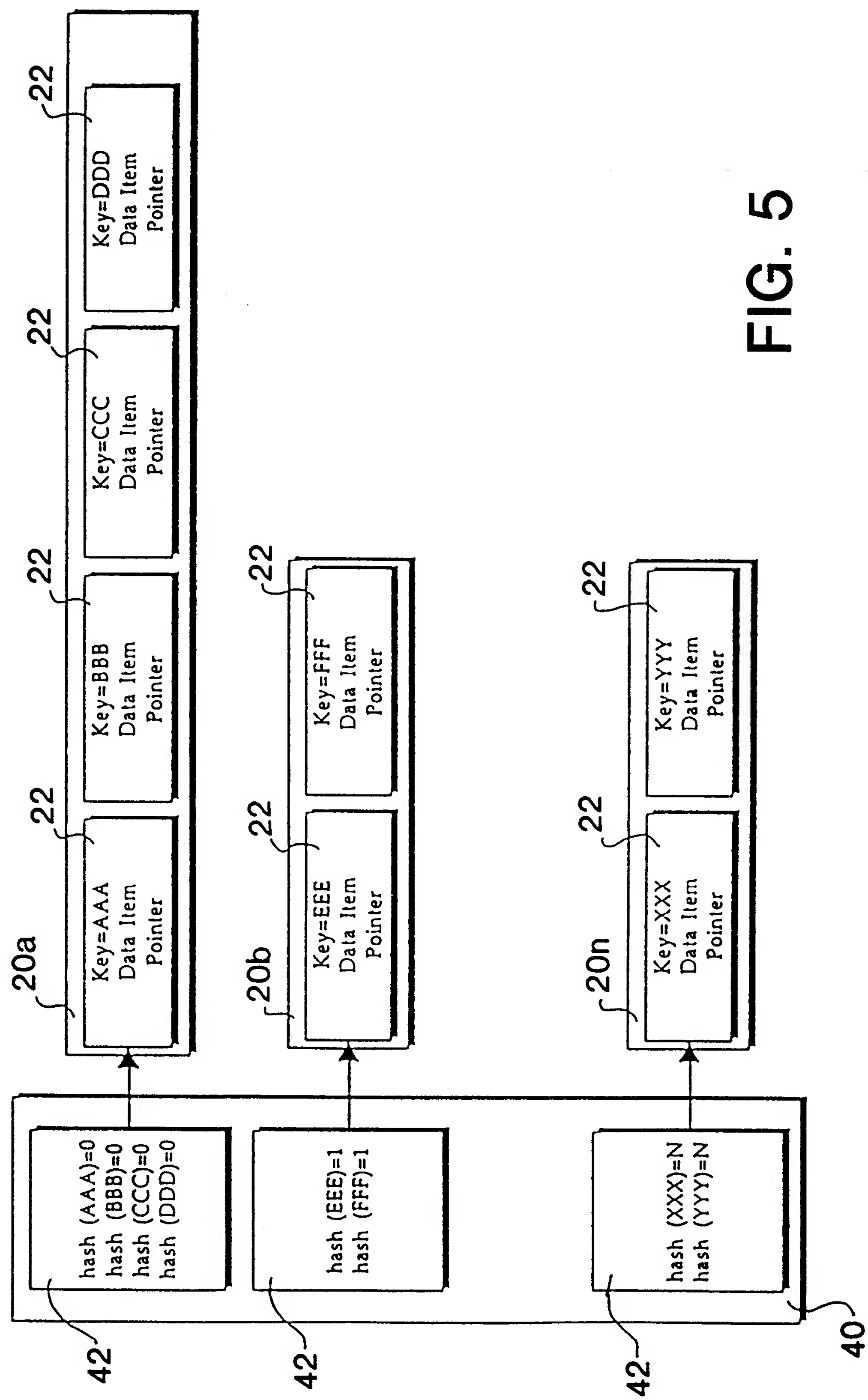

20a
Key=AAA
Data Item
Pointer
Key=BBB
Data Item
Pointer
Key=CCC
Data Item
Pointer
Key=DDD
Data Item
Pointer
20b
Key=EEE
Data Item
Pointer
Key=FFF
Data Item
Pointer
20n
Key=XXX
Data Item
Pointer
Key=YYY
Data Item
Pointer
22
hash (AAA)=0
hash (BBB)=0
hash (CCC)=0
hash (DDD)=0
hash (EEE)=1
hash (FFF)=1
hash (XXX)=N
hash (YYY)=N
42
40

FIG. 5

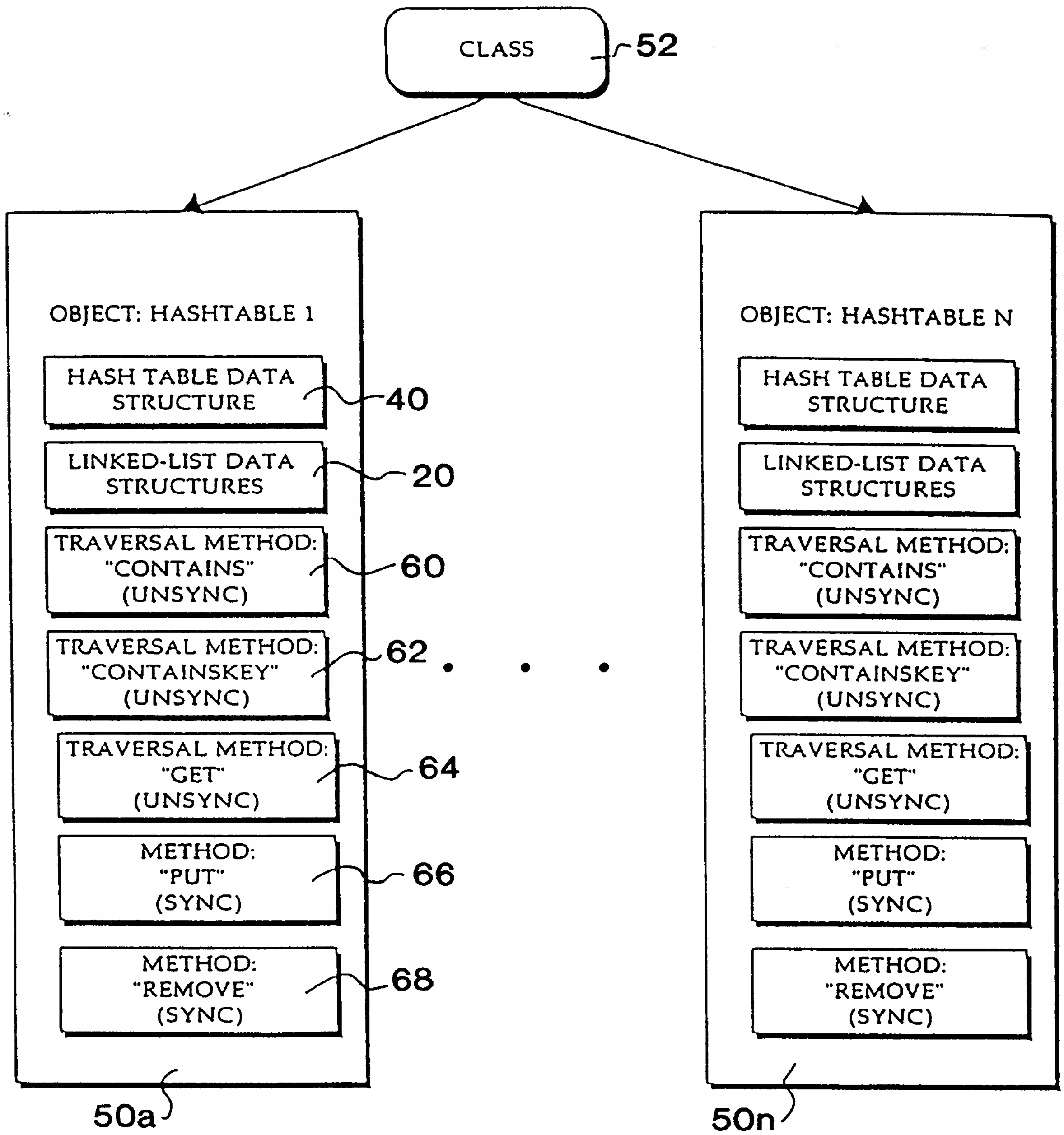
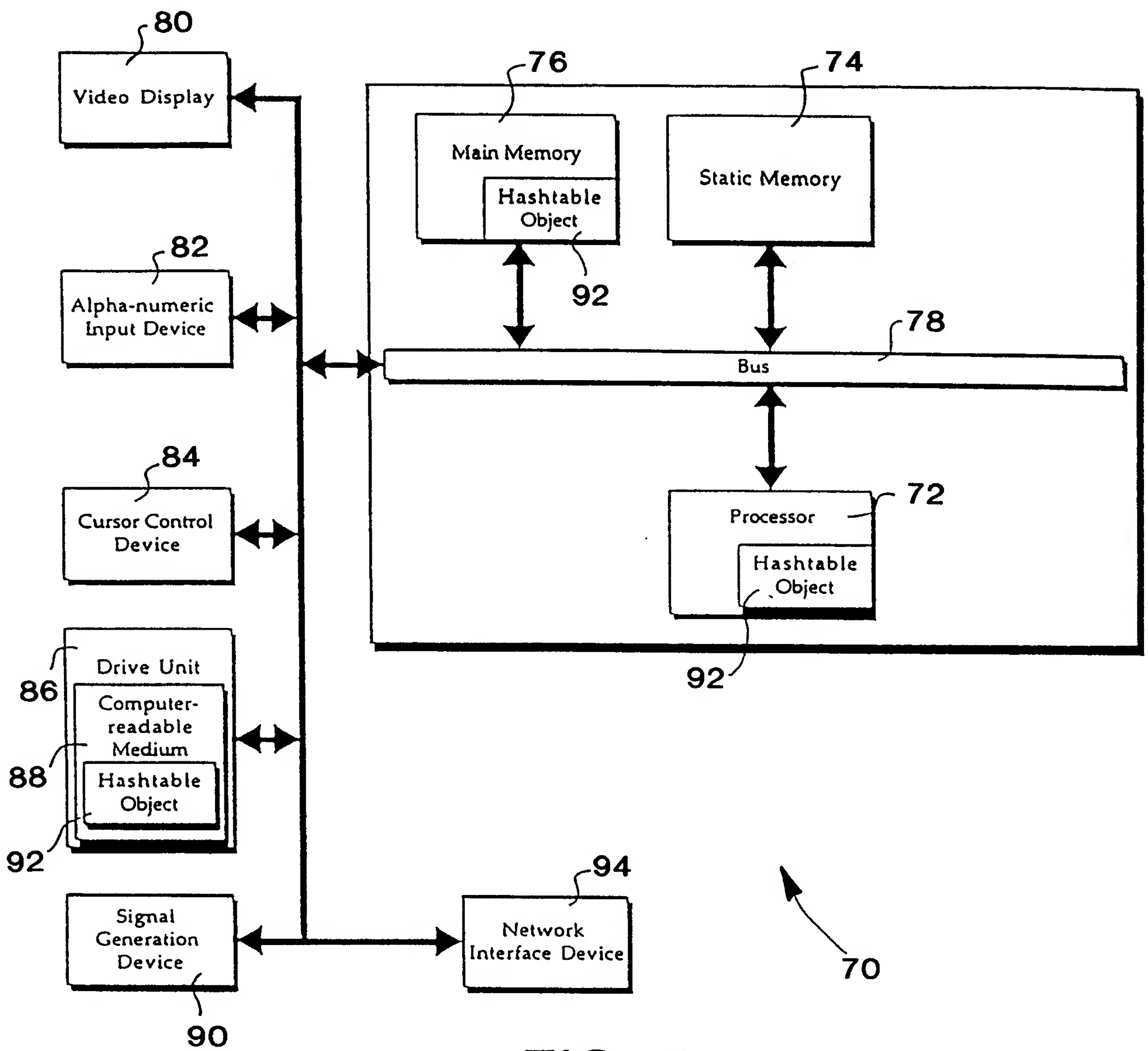

CLASS
52
OBJECT: HASHTABLE 1
HASH TABLE DATA STRUCTURE
40
LINKED-LIST DATA STRUCTURES
20
TRAVERSAL METHOD: "CONTAINS" (UNSYNC)
60
TRAVERSAL METHOD: "CONTAINSKEY" (UNSYNC)
62
TRAVERSAL METHOD: "GET" (UNSYNC)
64
METHOD: "PUT" (SYNC)
66
METHOD: "REMOVE" (SYNC)
68
50a
OBJECT: HASHTABLE N
HASH TABLE DATA STRUCTURE
LINKED-LIST DATA STRUCTURES
TRAVERSAL METHOD: "CONTAINS" (UNSYNC)
TRAVERSAL METHOD: "CONTAINSKEY" (UNSYNC)
TRAVERSAL METHOD: "GET" (UNSYNC)
METHOD: "PUT" (SYNC)
METHOD: "REMOVE" (SYNC)
50n

FIG. 6



80
Video Display
82
Alpha-numeric Input Device
84
Cursor Control Device
86
Drive Unit
88
Computer-readable Medium
Hashtable Object
92
Signal Generation Device
90
76
Main Memory
Hashtable Object
92
74
Static Memory
78
Bus
72
Processor
Hashtable Object
92
94
Network Interface Device
70

FIG. 7

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US98/13652

A. CLASSIFICATION OF SUBJECT MATTER
IPC(6) :GO6F 9/18, 15/40, 13/00, 12/14, 17/30, 13/14.
US CL :707/8, 100, 203, 206
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 707/8, 100, 203, 206

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
APS, IEEE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 4,149,243 A (WALLIS) 10 April 1979, col. 2, lines 1-52.	1-24
Y	US 5,168,554 A (LUKE) 01 December 1992, col. 2, lines 31-32.	1-24
Y	US 5,442,758 A (Slingwine et al) 15 August 1995, col. 5, lines 25-67.	1-24
Y	US 5,293,600 A (VRIEZEN) 08 March 1994, col. 3, line 30-col. 4, line 47).	1-24.
Y	US 5,469,567 A (OKADA) 21 November 1995, col. 3, lines 10-43.	1-24.
Y	US 5,495,609 A (SCOTT) 27 February 1996, col. 2, line 35-col. 3, line 35.	1-24

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier document published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search
18 SEPTEMBER 1998

Date of mailing of the international search report
29 OCT 1998

Name and mailing address of the ISA/US
Commissioner of Patents and Trademarks
Box PCT
Washington, D.C. 20231
Facsimile No. (703) 305-3230

Authorized officer
FRANTZ COBY
Telephone No. (703) 305-9707

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5,287,521 A (NITTA et al) 15 Febraury 1994, col. 3, lines 40-67.	1-24
Y	US 5,295,262 A (SEIGH, II) 15 March 1994, col. 2, lines 17-29.	1-24
Y	US 5,319,778 A (CATINO) 07 June 1994, col. 3, line 5-49).	1-24